

# TAU AIR-SHOWERS SIGNATURE OF ULTRA HIGH ENERGY NEUTRINOS

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## Abstract

The discover of Ultra High Energy Neutrino of astrophysical nature may be already reached. Indeed upward and horizontal  $\tau$  Air-showers emerging from the Earth crust or mountain chains offer the best and most powerful signal of Ultra High Energy UHE neutrinos  $\nu_\tau$ ,  $\bar{\nu}_\tau$  and  $\bar{\nu}_e$  at PeV and higher energy. The multiplicity in  $\tau$  Air-showers secondary particles,  $N_{opt} \simeq 10^{12}(E_\tau/PeV)$ ,  $N_\gamma(< E_\gamma > \sim 10 MeV) \simeq 10^8(E_\tau/PeV)$ ,  $N_{e^-e^+} \simeq 2 \cdot 10^7(E_\tau/PeV)$ ,  $N_\mu \simeq 3 \cdot 10^5(E_\tau/PeV)^{0.85}$  make easy its discover. UHE  $\nu_\tau$ ,  $\bar{\nu}_\tau$  following Super Kamiokande evidence of neutrino flavour mixing, ( $\nu_\mu \leftrightarrow \nu_\tau$ ), should be as abundant as  $\nu_\mu$ ,  $\bar{\nu}_\mu$ . Also anti-neutrino electrons,  $\bar{\nu}_e$ , near the Glashow W resonance peak,  $E_{\bar{\nu}_e} = M_W^2/2m_e \simeq 6.3 \cdot 10^{15} eV$ , may generate  $\tau$  Air-showers. Such horizontal  $\tau$  air-showers by  $\nu_\tau N$  and UHE  $\bar{\nu}_e e$  at PeV emerging from mountain high chain might be the most power-full UHE neutrino imprint. Upward UHE  $\nu_\tau - N$  interaction on Earth crust at horizontal edge and from below, their consequent UHE  $\tau$  air-showers beaming toward high mountains should flash  $\gamma, \mu, X$  and Cherenkov lights toward detectors located on the top of the mountain or balloons. Such upward  $\tau$  air-shower may hit also nearby satellite flashing them by short, hard, diluted  $\gamma$ -burst at the edge of Gamma Ray Observatory BATSE threshold. We identify already these rarest gamma events with recent (1994) discovered upward Terrestrial Gamma Flashes (TGF); we show their very probable UHE  $\tau$  -UHE  $\nu_\tau$  origin. Partial TGF Galactic signature and known galactic and extra-galactic source location are discovered within known 47 TGF events at low,  $\simeq 2 \cdot 10^{-3}$  probability threshold.

# 1 How UHE $\bar{\nu}_e$ , $\nu_\tau$ , $\bar{\nu}_\tau$ are in-written by Tau Air-showers

Ultra high energy astrophysical neutrino (UHE $\nu$ ) from PeVs ( $\gtrsim 10^{15}$  eV) up to ( $10^{18}$  eV) EeV and GZK cut off energies ( $\gtrsim 10^{19}$  eV) might be traced by  $\tau$  induced air showers and by their millions to hundred billions multiplicity in secondaries particles. Indeed astrophysical PeVs UHE anti-neutrino electrons,  $\bar{\nu}_e$ , near the Glashow W resonance peak,  $E_{\bar{\nu}_e} = M_W^2/2m_e \simeq 6.3 \cdot 10^{15}$  eV, (dominant over expected UHE PeV atmospheric neutrino signals), may be observable by their secondary horizontal  $\tau$  air showers originated by UHE chain reaction  $\bar{\nu}_e + e \rightarrow W^- \rightarrow \bar{\nu}_\tau + \tau^-$  inside the concrete rock of a high mountain and their consequent escape and decay in air flight. Also UHE  $\nu_\tau$ ,  $\bar{\nu}_\tau$  at ( $10^{16}$  -  $10^{17}$  eV) interacting with nuclear matter ( $\nu_\tau N$ ) must be observable because of flavor mixing  $\nu_\mu \leftrightarrow \nu_\tau$  shown by Superkamiokande data; indeed huge astrophysical distances are larger than the oscillation ones even for small mass differences (below  $\Delta m_{ij}^2 \sim 10^{-4}$  eV<sup>2</sup>). Therefore UHE  $\nu_\tau$  and  $\bar{\nu}_\tau$  may be converted and they may reach us from high energy galactic sources, as pulsars, Supernova remnants or galactic micro-quasars and SGRs, as well as from powerful extra-galactic AGNs, QSRs or GRBs, even at highest (GZK) energy because of the large galactic (Kpcs) and extreme cosmic (Mpcs) distances:

$$L_{\nu_\mu-\nu_\tau} = 4 \cdot 10^{-3} pc \left( \frac{E_\nu}{10^{16} \text{ eV}} \right) \cdot \left( \frac{\Delta m_{ij}^2}{(10^{-2} \text{ eV})^2} \right)^{-1} \quad (1)$$

These Tau air-showers are detectable in deep valleys or on front of large mountain chains as Alps, Rocky Mountains, Andes, (Fargion, Aiello, Conversano) (1999). The mountain and the air act as a fine tuning multi filter detector: as a screen of undesirable noisy UHECR showers (mainly electro-magnetic ones, Cherenkov photons, X, gamma and most of muons); as a dense calorimeter for UHE $\bar{\nu}_\tau$  nuclear events (three order of magnitude denser than air); as a distance meter target correlating  $\tau$  birth place and its horizontal air-shower opening origination with the cosmic ray energy density; as a characteristic anti neutrino detector by the extreme resonant cross section  $\bar{\nu}_e - e$  and the consequent fine-tuned energy (few PeV) shower events; as a very unique source of dense muon bundles from a mountain by main tau hadronic air-showering.

The vertical up-ward tau air-showers (by small arrival nadir angle) occur preferentially at low energies nearly transparent to the Earth ( $E_\nu \sim 10^{15} - 10^{16}$  eV). The oblique  $\tau$  air showers (whose arrival directions have large nadir angle), may be related also to higher energy  $\nu_\tau$ , or  $\bar{\nu}_\tau$  nuclear interactions ( $E_{\bar{\nu}_\tau} \geq 10^{17} - 10^{19}$  eV). Indeed these horizontal - upward UHE  $\nu_\tau$  cross a smaller fraction of the Earth volume and consequently they suffer less absorption toward the horizon. Moreover the consequent ultra-relativistic ( $E_{\bar{\nu}_\tau} \geq 10^{17} - 10^{19}$  eV) tau may travel in atmosphere for few or even hundred Kms with no absorption before the decay to the detector located at few Kms distance. On the contrary the horizontal gamma, electron pairs and muon showers by primary (down-ward nearly horizontal) UHECR proton are severely suppressed ( $\geq 10^{-3}$ ) after crossing ( $\geq 2 \cdot 10^3$ ) gm.cm<sup>-2</sup>, or equivalent at one atmosphere, ( $\geq 16$  Kms) of horizontal atmosphere target.

These huge horizontal or upward air-shower signals being at least million to billion times more abundant than the original and unique UHE  $\tau$  or UHE  $\mu$  track in underground Km cube detectors are much easier to be discovered with no ambiguity. These high energy PeVs tau air-shower are mainly of astrophysical nature. Indeed they cannot be produced by PeV atmospheric neutrino secondaries born in atmospheric muon flavour and oscillating in tau state, because their high PeV energy and their consequent large oscillation lengths are much (hundred times) longer than the Earth diameter. We remind that on the contrary the expected long tracks of upward muons in underground  $\text{km}^3$  detectors are mostly noisy signals by TeVs to tens of TeVs muons secondaries generated by atmospheric neutrinos born by common cosmic ray interactions in upper atmosphere. The real (looked for) astrophysical signals are upward PeV neutrino muons which are, unfortunately, suppressed by Earth opacity. This make cube Km detector, in our opinion, less favorite than our Tau up-ward air-shower detection. Let us remind that upward  $\nu_\tau$  at same energies as noted by different authors are less (an order of magnitude) suppressed. Present  $\tau$  air shower is analogous to the well-known Learned and Pakwasa (1995) "double bang" in underground neutrino detectors. The novelty of the present "one bang in" (the rock, the mountain, the Earth) - "one bang out" (the air) lays in the self-triggered explosive nature of  $\tau$  decay in flight and its consequent huge amplified air shower signal at a characteristic few Kms distance.

## 2 The peculiar UHE $\bar{\nu}_e$ , $\nu_\tau$ , $\bar{\nu}_\tau$ and $\tau$ interactions

Moreover the expected  $\nu_\tau$  signals, by their secondary tau tracks at highest cosmic ray energy window  $1.7 \cdot 10^{21} \text{ eV} > E_\tau > 1.6 \cdot 10^{17} \text{ eV}$ , must exceed the corresponding  $\nu_\mu$  (or muonic) ones, making UHE  $\nu_\tau$  above 0.1 EeV the most probable UHE signal. Indeed, the Lorentz-boosted tau range length grows (linearly) above muon range, for  $E_\tau \geq 1.6 \cdot 10^8 \text{ GeV}$ ; (see Fig (1) eq.3): the tau track reaches its maxima extension, bounded not by bremsstrahlung radiation length nor by pair production (eq. 2), but by growing nuclear (mainly photo-nuclear) and mainly, later, by electro-weak interactions (eq. 4),  $R_{\tau_{\text{max}}} \simeq 191 \text{ Km}$ , at energy  $E_\tau \simeq 3.8 \cdot 10^9 \text{ GeV}$  in water.

$$R_{R_\tau} \cong 1033 \text{ Km} \left( \frac{\rho_r}{5} \right)^{-1} \cdot \left\{ 1 + \frac{\ln \left[ \left( \frac{E_\tau}{10^8 \text{ GeV}} \right) \left( \frac{E_\tau^{\text{min}}}{10^4 \text{ GeV}} \right)^{-1} \right]}{(\ln 10^4)} \right\}. \quad (2)$$

$$R_{\tau_o} = c\tau_\tau \gamma_\tau = 5 \text{ Km} \left( \frac{E_\tau}{10^8 \text{ GeV}} \right). \quad (3)$$

$$R_{W_\tau} = \frac{1}{\sigma N_A \rho_r} \simeq \frac{2.6 \cdot 10^3 \text{ Km}}{\rho_r} \left( \frac{E_\tau}{10^8 \text{ GeV}} \right)^{-0.363}. \quad (4)$$

It should be noticed that the radiative  $\tau$  length estimated above has been considered for bremsstrahlung radiation length only. Pair production energy loss is more restrictive in the final  $R_{R_\tau}$  length (by an approximate factor  $\frac{m_\tau}{m_\mu}$ ) as well as the growing photo-nuclear interactions at highest (tens  $\text{EeV}$ ) energies. However the very dominant electro-weak interactions at these energies are already suppressing the  $\tau$  growth and the combined interaction length are slightly less, but almost comparable to the one shown in figure above.

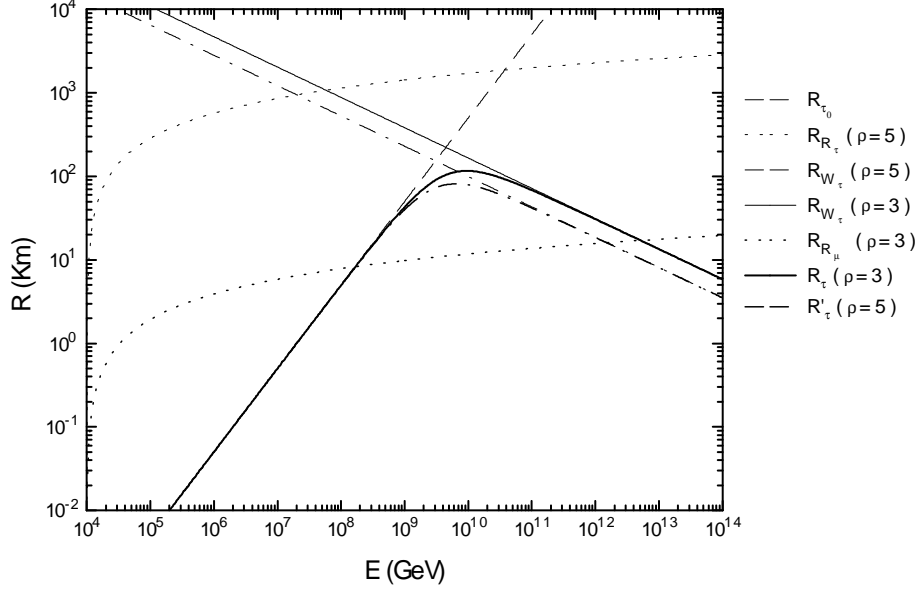


Figure 1: The tau ranges as a function of the tau energy respectively for tau lifetime (dashed line)  $R_{\tau_0}$ , for over-estimated tau radiation range  $R_{R_\tau}$ , (short dashed line above) and tau electro-weak interaction range  $R_{W_\tau}$ , for two densities  $\rho_r$  (long dashed lines, continuous) and their combined range  $R_\tau$ . Below the corresponding radiation range  $R_\mu$  for muons (dotted line).

At the peak maxima the tau range is nearly 10-20 times longer than the corresponding muon range (at the same energy) implying, for comparable fluxes, a ratio 10 times larger in  $\nu_\tau$  over  $\nu_\mu$  detection probability. This dominance, may lead to a few rare spectacular event a year (if flavor mixing occurs) preferentially in horizontal plane in underground  $Km^3$  detectors. The Earth opacity at those UHE regimes at large nadir angles (nearly horizontal, few degree upward direction) is exponentially different for UHE muons respect to tau at GZK energies (corresponding to hundreds Kms UHE Tau lengths), making the muon/tau flux ratio of such lengths severely suppressed. Unfortunately there are not yet in underground detector such possible tests; maybe in new generation horizontal slice detectors of tens Km sizes the UHE GZK  $\tau$  may dominate by such lengths and huge showering. The ratio among these  $\nu_\tau$  over  $\nu_\mu$  tens Kms signals is exponentially high  $> \exp(10)$ .

### 3 The key role of UHE $\nu$ , interactions with the relic $\bar{\nu}$ at $Z$ resonance in hot dark haloes

In the frame-work of UHE neutrino astrophysics it is important to remind the very peculiar role that heaviest light neutrino (most probably of tau nature) may play in the puzzling GZK problem in modern high energy astrophysics. Indeed let us remind here a possible additional (and parental) role of UHE  $\nu$  above GZK discussed in this article. UHE  $\nu_\tau$  at energies near or above GZK energies are transparent to BBR cosmic photons (contrary to common nucleons, nuclei, photons UHECR); therefore neutrinos may easily reach us from far cosmological distances. Then the puzzle of UHECR above GZK cut off may be solved assuming that neutrinos (possibly of heaviest muon-tau nature) share a light mass of few eV, in the frame-work of Hot Dark Matter halos clustered around galaxies or local group. Such light neutrinos may form a huge hidden dark calorimeter able to beam dump UHE  $\nu$  via  $Z$  (s-channel), via virtual  $W$  ( $t$  channel) or  $W$  and  $Z$  pair productions. The latter cross-sections are less efficient than the  $Z$  (s-channel) but are not fine tuned or restricted on a (very light, nearly half eV) relic neutrino mass. The corresponding cross sections for such  $\nu \nu$  interactions are shown in Fig. 2; their secondaries may be final UHE anti-protons (or anti-neutrons) or UHE protons (or neutrons) (Fargion, Mele, Salis 1997-1999) responsible of final observed UHECR above GZK cut off. The interaction efficiency by relic light neutrinos via UHE  $\nu$  at GZK cut off is thousands times larger than UHE  $\nu$  interactions on Earth atmosphere and/or direct UHECR (nucleons, nuclei) propagation above GZK distances. Therefore light neutrino mass may explain both hot dark matter and UHECR above GZK (as well as their recent arrival clustering in triplets or doublets). If this solution is correct we are already testing both the neutrino mass the relic neutrino density and the UHE neutrino flux. Just to underline the  $\nu$  mass roles of a few eV in modern high energy astrophysics we remind also the important case of a SN ejected neutrino burst (at MeVs energies) arriving slowed by its mass relativistic flight and delayed respect to the arrival of the massless prompt super-nova gravitational burst. The expected time delay between the massive neutrino with the massless graviton wave burst, offer an additional test to the elusive neutrino mass detection:

$$\Delta t \sim 50 \text{ sec} \left( \frac{E_\nu}{5 \text{ MeV}} \right)^{-2} \left( \frac{m_\nu}{5 \text{ eV}} \right)^2 \left( \frac{L}{Mpc} \right). \quad (\text{Fargion 1981}).$$

#### 3.1 Horizontal $\tau$ air-shower born on front of mountain chain: UHE PeVs neutrino trace

Therefore UHE Tau  $E_\tau \geq 10^5 \text{ GeV} - 5 \cdot 10^7 \text{ GeV}$  air-shower in front of high mountains chains will be easily induce peculiar horizontal UHE  $\tau$  (Fargion, Aiello, Conversano 1999). Energies above will be probably missed. An hybrid detector (gamma/optical air-shower array) would get precise signal and arrival direction. Because of the different neutrino interactions with energy it will be possible to estimate, by stereoscopic, directional and time structure signature, the spatial air-shower origination in air, the primary tau distance decay from the mountain (tens or a hundred of meters for fine tuned PeVs UHE  $\bar{\nu}_e$  and meters up to few Kms for UHE  $\nu_\tau, \bar{\nu}_\tau$  at wider energy window  $E_\tau \geq 10^5 \text{ GeV} - 5 \cdot 10^7 \text{ GeV}$ . Additional energy calibration may be derived sampling shower intensities.

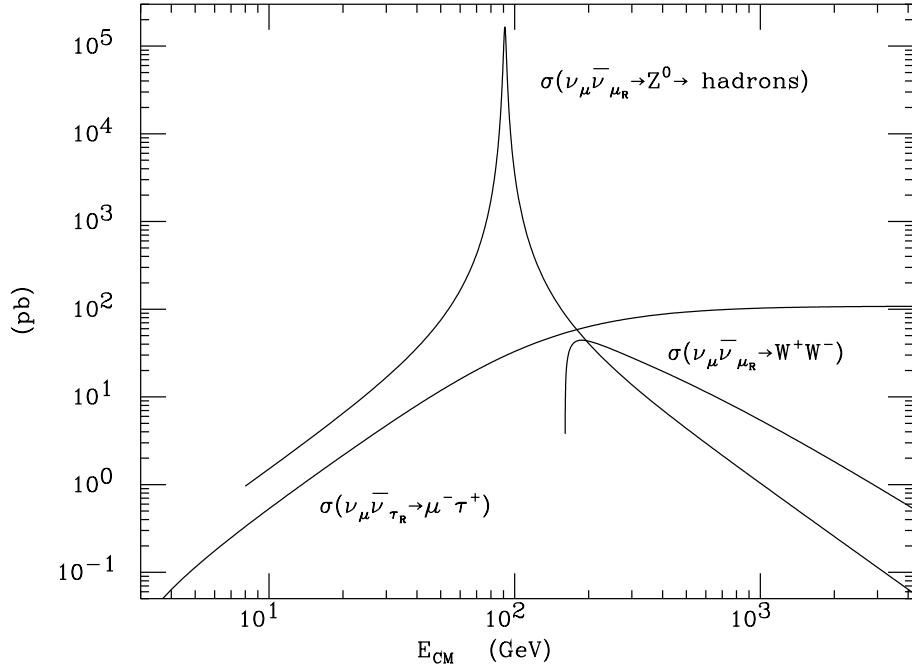


Figure 2: The total cross sections for the UHE  $\nu\bar{\nu}$  indicated processes as function of the center of mass energy (Fargion,Mele,Salis 1999)

Hundreds of array (scintillator,Cherenkov) detectors in deep wide valley horizontally oriented would be necessary to get tens  $\tau$  air-showers events a year. Screening by undesirable lateral or downward noisy cosmic rays or natural radiation is achieved by directional and time clustering filter; the induced  $\bar{\nu}_e e \rightarrow \tau$  air shower even in absence of  $\nu_\mu \leftrightarrow \nu_\tau$  oscillation should be well identified and detectable. The atmospheric  $\bar{\nu}_e$  ones (secondary by common UHECR) are suppressed by a severe power law . Its unique  $\bar{\nu}_e$  origin is marked by the peaked W resonance, and by the small mountain  $\bar{\nu}_e$  opacity and its high neutrino cross-section. Its identity is marked by the expected fine tuned PeV energy at W peak.

More copious ( $> 5$  times more) events by PeV up to tens PeV charged current  $\nu_\tau N$  interaction occur following Super Kamiokande flavour mixing discover.

### 3.2 Upward $\tau$ PeV-EeV air-showers flashing to high mountains, balloons and satellites

It will be also possible to observe UHE  $\nu_\tau$ , by the upward tau air-shower arriving from tens or hundred Kilometers away (near horizontal edges) from high mountains, high balloon and satellites; such UHE tau created within a wide (tens thousands to millions square km<sup>2</sup> wide and hundred meter UHE Tau depth in Earth crust) target would discover only UHE  $\nu_\tau, \bar{\nu}_\tau$  neutrinos at PeV up to EeV energies and above, just within the mysterious GZK frontiers. The discover will need capable gamma, optical and mainly

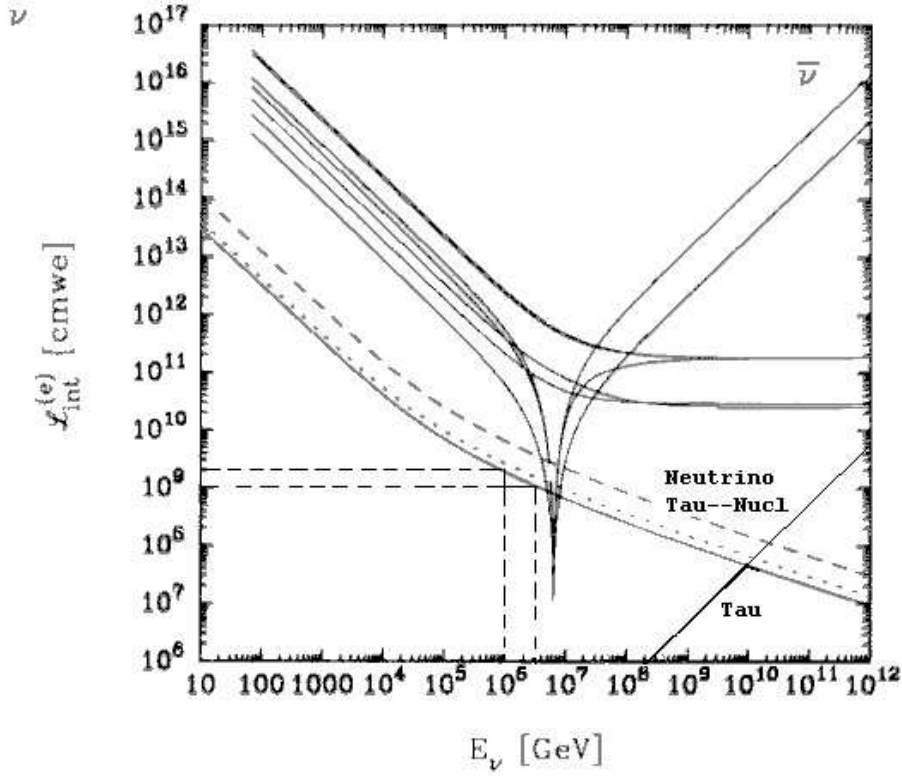


Figure 3: The Gandhi et al (1998) UHE neutrino ranges as a function of UHE neutrino energy in Earth with overlapping the resonant  $\bar{\nu}_e e$ ,  $\nu_\tau N$  interactions; below in the corner the UHE  $\tau$  range, as in Fig 1, at the same energies in matter (water).

muon bundle detectors within present technology .

From the same highest mountains, balloons and near orbit satellite, looking more downward toward the Earth it is possible to discover more frequent but lower energetic astrophysical  $\simeq$  PeV - tens PeV neutrinos still nearly transparent to the Earth volume (Gandhi et al. 1998), (see Fig.3).

The UHE neutrinos  $\bar{\nu}_e, \nu_\mu$   $\bar{\nu}_\mu$  are default and expected UHECR ( $\gtrsim 10^{16}$  eV) secondary products near AGN or micro-quasars by common photo-pion decay relics by optical photons nearby the source (PSRs, AGNs) ( $p + \gamma \rightarrow n + \pi^+$ ,  $\pi^+ \rightarrow \mu^+ \nu_\mu$ ,  $\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$ ), or by proton proton scattering in galactic interstellar matter. The maximal observational distances from mountains, balloons or satellites, may reach  $\sim 110$  Km  $(h/Km)^{\frac{1}{2}}$  toward the horizon, corresponding to a UHE  $\tau$  energy  $\sim 2 \cdot 10^{18}$  eV  $(h/Km)^{\frac{1}{2}}$ . Therefore we propose to consider such upward shower nearly horizontal detection from high mountains to test this highest  $\nu_\tau \bar{\nu}_\tau$  energy window almost opaque to Glashow UHE  $\bar{\nu}_e$  fluxes just comparable to the GZK cut off energies.

The expected downward muon number of events  $N_{ev}(\bar{\nu}_e e \rightarrow \bar{\nu}_\mu \mu)$  in the resonant energy range, in Km<sup>3</sup>, [Table 7, The Gandhi et al, 1998] was found to be  $N_{ev} = 6$  a year. One expect a comparable number of reactions ( $\bar{\nu}_e e \rightarrow \bar{\nu}_\tau \tau$ ). However the presence of primordial  $\nu_\tau$ ,  $\bar{\nu}_\tau$  by flavor mixing and  $\nu_\tau$ ,  $\bar{\nu}_\tau N$  charged current interactions lead to a

factor 5 larger rate,  $N_{ev} = 29$  event/year.

If one imagines a gamma/optical detector at 5 km far in front of a chain mountain as the Alps Argentier valley (size 10 km, height 1 km) one finds a  $\tau$  air shower volume observable within a narrow beamed cone (Moliere radius  $\sim 80$  m / distance  $\sim 5$  Km): ( $\Delta\theta \sim 1^\circ$ ,  $\Delta\Omega \sim 2 \cdot 10^{-5}$ ) and an effective volume  $V_{eff} \simeq 9 \cdot 10^{-5}$  Km<sup>3</sup> for each observational detector. Each single detector is comparable to roughly twice a Super Kamiokande detector. Following common AGN - SS91 model [The Gandhi et al,1998] we foresee a total event rate of: (6)  $(\bar{\nu}_e e) + (29) (\nu_\tau N) = 35$  UHE  $\nu_\tau$  event/year/Km<sup>3</sup>. At energies above 3 PeV we may expect a total rate of  $N_{ev} \sim 158$  event/year in this Alps Argentiere mountains valley and nearly  $3.2 \cdot 10^{-3}$  event/year for each m<sup>2</sup> size detector. In a first approximation, neglecting Earth opacity, it is possible to show that the Earth volume observable from the top of a mountain at height  $h$ , due to UHE  $\tau$  at 3 PeV crossing from below, is approximately  $V \approx 5 \cdot 10^4$  Km<sup>3</sup>  $\left(\frac{h}{Km}\right) \left(\frac{E_\tau}{3 PeV}\right)$ . These upward shower would hit the top of the mountain. For the same  $\tau$  air shower beaming ( $\Delta\theta \sim 1^\circ$ ,  $\Delta\Omega \sim 2 \cdot 10^{-5}$ ) we derive now an effective volume  $\sim 1$  Km<sup>3</sup>. Therefore a detector open at  $2\pi$  angle on a top of a 2 Km height mountain may observe nearly an event every two month from below the Earth. The gamma signal above few MeV would be (depending on arrival nadir angle) between  $3 \cdot 10^{-2}$  cm<sup>-2</sup> (for small nadir angle) to  $10^{-5}$  cm<sup>-2</sup> at far distance within 3 PeV energies. A contemporaneous (microsecond) optical flash ( $\gtrsim 300 \div 0.1$  cm<sup>-2</sup>) must occur. Keeping care of the Earth opacity, at large nadir angle ( $\gtrsim 60^\circ$ ) where an average Earth density may be assumed ( $\langle \rho \rangle \sim 5$ ) the transmission probability and creation of upward UHE  $\tau$  is approximately

$$P(\theta, E_\nu) = e^{-\frac{2R_{Earth} \cos \theta}{R_{\nu\tau}(E_\nu)}} (1 - e^{-\frac{R_\tau(E_\tau)}{R_{\nu\tau}(E_\nu)}}). \quad (5)$$

This value, at PeV is within a fraction of a million ( $\theta \approx 60^\circ$ ) to a tenth of thousands ( $\theta \approx 90^\circ$ ). The corresponding angular integral effective volume observable from a high mountain (or balloon) at height  $h$  (assuming a final target terrestrial density  $\rho = 3$ ) is:

$$V_{eff} \approx 0.3 Km^3 \left(\frac{\rho}{3}\right) \left(\frac{h}{Km}\right) e^{-\left(\frac{E}{3 PeV}\right)} \left(\frac{E}{3 PeV}\right)^{1.363} \quad (6)$$

A popular "blazar" neutrino flux model (like Stecker Salomon, Berezhinsky ones) normalized within a flat spectra (at an energy fluence  $\simeq 2 \cdot 10^3 eV$  cm<sup>-2</sup>) is leading, above 3 PeV, to  $\sim 10$  UHE  $\nu_\tau$  upward event/Km<sup>3</sup> year. Therefore we must expect an average upward effective event rate observed on a top of a mountain ( $h \sim 2 Km$ ) (Fig. 4):

$$N_{eff} \simeq 8 \frac{\text{events}}{\text{year}} \left(\frac{\rho}{3}\right) \left(\frac{h}{2 Km}\right) e^{-\left(\frac{E}{3 PeV}\right)} \left(\frac{E}{3 PeV}\right)^{1.363} \quad (7)$$

This rate is quite large and one expected  $\tau$  air air-shower signal (gamma burst at energies  $\gtrsim 10 MeV$ ) should be  $\phi_\gamma \simeq 10^{-4} \div 10^{-5}$  cm<sup>-2</sup>, while the gamma flux at ( $\sim 10^5 eV$ ) or lower energies (from electron pair bremsstrahlung) may be two order of magnitude larger. The optical Cherenkov flux is large  $\Phi_{opt} \approx 1$  cm<sup>-2</sup>.



## 4 Upward $\tau$ Air Shower in Terrestrial Gamma Flash: first evidences of UHE neutrinos

The tau upward air showers born in a narrow energy window,  $10^{15} \text{ eV} \lesssim E_\nu \lesssim 5 \cdot 10^{16} \text{ eV}$  (Fig.3) may penetrate high altitude leaving rare beamed upward gamma shower bursts whose sharp ( $\sim$  hundreds  $\mu\text{sec}$  because of the hundred kms high altitude shower distances) time structure and whose hard ( $\gtrsim 10^5 \text{ eV}$ ) spectra may hit near terrestrial satellites. We claim (Fargion 2000) that such gamma upward events originated by tau air showers produce gamma bursts at the edge of GRO-BATSE sensitivity threshold. In particular we argue that very probably such upward gamma events have been already detected since April 1991 as serendipitous sharp ( $\lesssim 10^{-3} \text{ sec}$ ) and hard ( $\gtrsim 10^5 \text{ eV}$ ) BATSE gamma triggers originated from the Earth and named consequently as Terrestrial Gamma Flashes (TGF).

### 4.1 Time asymmetry in down-ward and up-ward Tau Air-shower

Upward and Downward air-showers **are not symmetric** event at all because the different atmosphere densities at sea level and high altitude. Indeed at sea level  $\tau$  air-shower holds just a  $\mu\text{seconds}$ . But at high level  $\tau$  decays to produce millisecond showers. The arrival time of  $\gamma$  air-shower (bremsstrahlung photons) is ruled by the last atmosphere distances where the gamma emission has been originated (while being nearly unabsorbed). The mean energy deposition profile in air shower is given by a common gamma distribution:

$$\frac{dE}{dt} = \frac{E_0 b (bt)^{a-1} e^{-bt}}{\Gamma(a)} \quad (8)$$

where the a-dimensional shower depth distance  $t = \frac{x}{X_0}$  and the a-dimensional energy  $y = \frac{E}{E_c}$ , are well known variables. The characteristic critical energy  $E_c$  (see B. Rossi or Longair text book) is, in air, around 100 MeV value. The air shower maxima occurs at an a-dimensional depth  $t_{max} = \frac{a-1}{b}$ , while the characteristic shower distance  $X_s \equiv \frac{X_0}{b}$ , being  $b \simeq 0.5$ , is  $X_s \simeq 2X_0$ ; (note that  $t_{max} = \frac{a-1}{b} \simeq (\ln y + \frac{1}{2})$  defines  $a$  for a photon-induced cascades). Naturally the radiation length  $X_0$  is the same for upward and downward air showers. However the corresponding length distances are very different because the different altitudes (sea level and high altitude) where the shower takes place, have extremely different densities. The air density decreases, respect to the sea level height, with altitude  $z$  as  $\rho = \rho_0 e^{-\frac{z}{h_0}}$ ,  $h_0 \simeq 8.55 \text{ Km}$ . If one considers the sea level case  $X_0 = 36.6 \text{ g/cm}^2$  and the radiation distance is  $X_0 = 304.2 \text{ m}$ , the shower length is  $X_s \simeq 608.4 \text{ m}$  and the corresponding shower scale time is (as it is well known and as it is observed in common downward air showers)  $t_s = \frac{X_s}{c} \simeq 2\mu\text{s}$ . If now we consider upward  $\tau$  air shower arising on the top atmosphere altitude, than the same  $X_0 = 36.6 \text{ g/cm}^2$  corresponds, in a more diluted upward atmosphere to distances  $X'_0 \simeq 22 \text{ km}$  and in a first approximation to a shower length  $X'_s \simeq 44 \text{ km}$  leading to  $t'_s \simeq 75 t_s \sim 0.15 \text{ ms}$ . Additional time dilution must be considered for the arrival nadir angle  $\theta$ :  $t'_s \sim \frac{0.2}{\cos \theta} \text{ ms}$  and for geo-magnetic Larmor precession of relativistic electrons. More precisely, the  $\tau$  air shower timing is related to the total distance from the earliest atmosphere

last scattering ( $X_0 \sim 36.6 \text{ g/cm}^2$  and  $h \simeq 22 \text{ km}$ ) up to the BATSE satellite height ( $\sim 500 \text{ km}$ ). To summarize the maximal upward  $\tau$  air shower extend up to  $t'_s \sim \frac{500}{c \cos \theta} \text{ km} > 2 \text{ ms}$ .

The exponential density decay in upper atmosphere makes most of the bremsstrahlung radiation generated at lowest (tens of kms altitudes) implying a fast raise of the gamma flash within a few tens of millisecond, (as the observed TGF ones) even if the gamma signal must also extend up to few millisecond times as indeed observed in TGFs. Different Tau Air-shower Channel (as well known in particle data text) and their consequent bifurcation may lead to rapid TGF millisecond timing modulations as the observed ones.

## 4.2 Why the Terrestrial Gamma Flash are Tau Air-Showers

The visible Earth surface from a satellite, like BATSE, at height  $h \sim 400 \text{ Km}$  and the consequent effective volume for UHE  $\nu_\tau N$  PeVs interaction and  $\tau$  air shower beamed within  $\Delta\Omega \sim 2 \cdot 10^{-5} \text{ rad}^2$  is: (note  $< \rho > \simeq 1.6$  because 70 % of the Earth is covered by seas)  $V_{eff} = V_{TOT} \Delta\Omega \simeq 60 \text{ Km}^3$ . The effective volume and the event rate should be reduced, at large nadir angle ( $\theta > 60^\circ$ ) by the atmosphere depth and opacity (for a given  $E_\tau$  energy). Therefore the observable volume may be reduced approximately to within  $15 \text{ Km}^3$  values and the expected UHE PeV event rate is

$$N_{ev} \sim 150 \cdot e^{-\left(\frac{E_\tau}{3 \text{ PeV}}\right)} \left(\frac{E_\tau}{3 \text{ PeV}}\right)^{1.363} \left(\frac{h}{400 \text{ Km}}\right) \frac{\text{events}}{\text{year}} \quad (9)$$

The TGF signals would be mainly  $\gamma$  at flux  $10^{-2} \text{ cm}^{-2}$  at X hundred keV energies. The observed TGF rate is lower than the expected one (eq. 7) by nearly an order of magnitude, and this suggests higher  $E_\nu$  energies (to overcome BATSE threshold) and consequently small additional probability suppression fitting the observed TGF events rate. However since 1994 (Fishman et al.) TGF understanding of presently known 75 records over nearly eight thousand BATSE triggers is based on an unexpected and mysterious high latitude lightening of geophysical nature (the so called "Sprites" or "Blue Jets"). We do not believe in that interpretation. We notice that among the 75 records only 47 are published in their details, while 28 TGF are still unpublished. Their data release is therefore urgent and critical. While Blue Jets might be in principle triggered by upward tau air showers in the atmosphere (a giant "Wilson" room) we believe they are not themselves source of TGF. In particular their observed characteristic propagation velocity ( $\lesssim 100 \text{ Km/s}$ ) from distances  $\sim 500 \text{ Km}$ , disagree with short TGF millisecond timing and would favor a characteristic TGF time of few seconds.

Moreover TGF data strongly dis-favor by its hard spectra the terrestrial Sprites connection. On the contrary the expected UHE tau upward air showers lead to a gamma burst flux, spectra, and fine time structure fluence in agreement with the observed TGF ones and in agreement with the expected flux models. The correlations of these clustered TGFs directions toward

(1) well known and maximal powerful galactic and extra-galactic sources either at TeV, GeV-MeV, X band ,(2) recent first anisotropy discovered on UHECR at EeV by AGASA, (see Fig.4, from Hayashida et al. 1999) (3) the Milky Way Galactic Plane (Fig. 4), support and make compelling the TGF identification as secondary

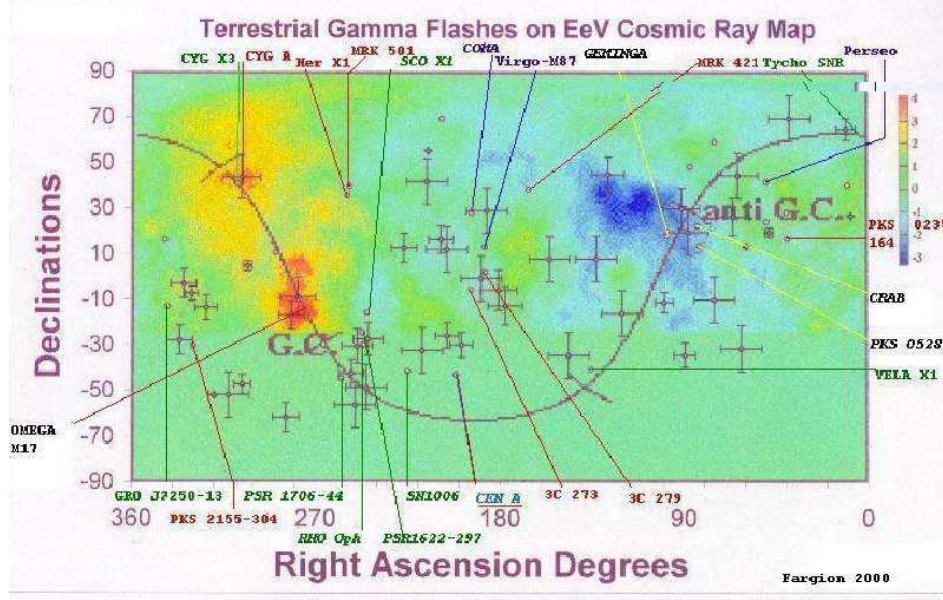


Figure 4: Terrestrial Gamma Flash in celestial coordinate over UHECR diffused data by AGASA cosmic rays at EeV energies. Known powerful Galactic and Extra galactic sources, very active at  $X, \gamma, TeV$ , possibly related to the TGF events are also shown by labels.

gamma burst tail of UHE  $\tau$  induced upward air shower. The present TGF- $\tau$  air-shower identification could not be produced by UHE  $\bar{\nu}_e$  charged current resonant event at ( $E_{\bar{\nu}_e} = M_W^2/2m_e = 6.3 \cdot 10^{15}$  eV), because of the severe Earth opacity for such resonant  $\bar{\nu}_e$ , and therefore it stand for the UHE  $\nu_\tau \bar{\nu}_\tau$  existence. Consequently it gives support to the Superkamiokande evidences for  $\nu_\mu \leftrightarrow \nu_\tau$  flavor mixing from far PSRs or AGNs sources toward the Earth. At the present the very probable  $\nu_\tau \bar{\nu}_\tau$  source of TGFs and their probable partial galactic location infer a first lower bound on  $\Delta_{m_{\nu_\mu \nu_\tau}}$  ( $L < 4$  Kpc,  $\Delta_{m_{\nu_\mu \nu_\tau}} > 10^{-8}$  eV<sup>2</sup>) and it offers a first direct test of the same existence of the last evanescent (hardly observed only recently), fundamental neutral lepton particle:  $\nu_\tau$  and  $\bar{\nu}_\tau$ .

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